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Summary

In the broadcast television environment, interlaced scanning is universal, although the advantage it has over the inherently simpler sequential scan is not obvious. By examining the fundamentals of television scanning in frequency–domain terms, it is concluded that the main benefit of interlaced scanning is that it is better matched to the slow roll-off vertical frequency characteristic of the cathode- ray tube with the result that the line structure is less noticeable.

With the advances in technology, other methods of improving the displayed picture quality can be considered, such as up-conversion in the display to higher line and field rates. However, this conversion process would be considerably simpler with a sequential input to the display unit and might more successfully overcome the movement problems of interlaced scanning in which vertical and temporal frequencies are difficult to distinguish.

This preference for a sequential input to the display unit brings with it a desirability to broadcast and possibly also to originate the television signals in sequential form. Moreover, in this context, it is considered that sequential scanning may have further advantages, both simplifying down-conversion from a higher scanning rate used in the camera and making low field-rate, movement compensated bandwidth compression techniques more effective. It is concluded, therefore, that sequential scanning may have an important part to play in the development of future television systems.

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1. INTRODUCTION

While sequential or, as it is sometimes known, progressive scanning is the simplest, most obvious system, interlaced scanning is used universally for broadcast television systems. At the time of their development, therefore, interlaced scanning had some advantage. What led to this supremacy? Did it arise from fundamental properties of human vision or was it the result of being better suited to the prevailing technology? If it was the latter, then the development of new techniques may have altered the balance to make sequential scanning more attractive. While for today's television this is academic speculation, in the context of new television systems in which different scanning methods could be adopted in different parts of the signal chain, it is appropriate to reassess the merits of the two systems.

Although some forms of interlace had been considered earlier[1], interlace in its modern form[2] was adopted in the early 1930's. This was a time of rapid advances in many aspects of television, but particularly in the development of the cathode-ray tube (CRT) display. Brighter CRT displays made flicker from the 180-line, 25 fields per second sequential scanning of the day unacceptable. Also, the search for greater definition, coupled with finer focussing of the CRT spot, led to successive increases in the number of lines per field[1]. This prompted the development of a 50 Hz interlaced scan, first with 343 and then 405 lines per picture. While the suppression of flicker was almost certainly the predominant factor in this choice of scanning systems, a similar effect could have been obtained simply by increasing the field rate of sequential scan.

What then is the main advantage of interlace? Asking broadcasting engineers "What is the purpose of interlace in a television system?" gives a variety of answers. Some say it is to reduce bandwidth, others say it gives more lines to increase vertical resolution, or it reduces the visibility of aliases by giving them a temporal component, or it provides a better match to the spatio-temporal acuity of the eye. Several other explanations could be given. As the answers are made in comparative terms, the many different views partly result from different assumptions about which sequential scanning option is the most equivalent to a particular interlaced standard. Deciding which sequential system is most equivalent to, for example, the 625-line, 50-fields per second, interlaced standard (625/50/2:1) may help reveal the purpose of interlace.

Three sequential systems have a measure of equivalence through sharing either the same number of lines per picture, or fields per second, or both. These are 625/50/1:1, 625/25/1:1 and 312/50/1:1. The most acceptable, from a picture quality viewpoint, is probably 625/50/1:1 which has the same line pitch and large-area flicker frequency as 625/50/2:1. However, twice the bandwidth is required, which is a high price to pay for the removal of the interlace defects such as inter-line twitter and line crawl. If we consider a 625/25/1:1 system, this has the same bandwidth requirement as the interlaced system and the same line pitch, but in its direct form it would be unwatchable because of flicker. The fields could be repeated to double the flicker rate, but unless the electronic camera were 'shuttered', as with cine film, the integration time would be twice normal, resulting in very blurred movement. Even if shuttering were used, the portrayal of movement would only have the quality currently provided by film. The alternative of 312/50/1:1 scanning would give good movement performance, but depending on the resolution of the display, would either be very lacking in vertical resolution or would have an obvious line structure.

So interlace has clear advantages over all the potentially equivalent sequential systems; but what particular feature makes it better? To try and answer this, the next section examines the workings of television in more detail and an area of greater similarity to one of these sequential systems is revealed. The discussion is then extended to developments of the basic system that might result from the application of new techniques and improved technology. Finally, the degree to which these arguments can be extended to other scanning rates is considered.

2. TELEVISION FUNDAMENTALS

2.1. Filtering in television scanning

The actions of the television camera tube, in scanning the image, and the display, subsequently reproducing a continuous representation of the image from the discrete lines and fields of the signal, are depicted in Fig. 1(a). These can be likened to the analogue-to-digital (A-D) and digital-to-analogue (D-A) conversions of a PCM system, shown in Fig. 1(b). Comparing these processes, it falls to the camera to produce the pre-sampling low-pass filter action of the A-D converter, and the combination of the CRT

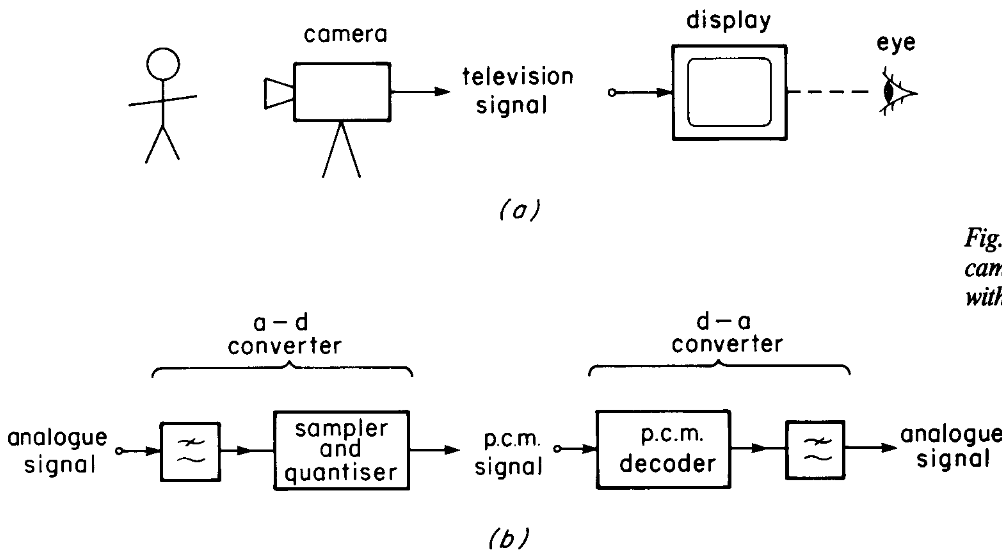

Fig. 1 - Comparison (a) of the camera and display/eye combination with (b) the A-D and D-A converters of a PCM system.

display and the eye to provide the low-pass filtering of the D-A converter. In a digital sampling system for PCM, it is relatively straightforward to provide near-ideal rectangular filters which virtually eliminate the possibility of aliasing. In contrast, the filtering action of the camera and the display are far from 'ideal' in the rectangular sense and can leave even the sampling frequencies (the line and field frequencies) still clearly visible.

A television camera operating on the 625/50/2:1 standard normally integrates the light from the image for one fiftieth of a second (20 ms). This is because the scanning spot extends over a width of several lines, thus approximately discharging both the first and second field line positions on each scan. This results in a 'sinc' characteristic for the temporal pre-sampling filter, as shown in Fig. 2(a). Filtering in the vertical dimension is determined by the scanning spot profile which, although being a complicated asymmetrical shape, can be assumed to result in a roughly Gaussian, slow roll-off frequency characteristic. Because of the spread of the spot, the vertical resolution is considerably reduced above 156 cycles per picture height (c/p.h.) with virtually no response beyond 312 c/p.h., as shown in Fig. 2(b).

To avoid an obvious line structure, it is necessary to match the line pitch to the vertical resolution of the display. The filtering effect of the display is determined by the profile of the CRT scanning spot which, being approximately Gaussian, again produces a slow roll-off vertical frequency characteristic. The line structure can be suppressed to any required degree by adjusting the spot focus, although when the lines are invisible, there will inevitably be some attenuation of higher passband frequencies as well. Fig. 3 shows a representative vertical characteristic in which the frequency of the

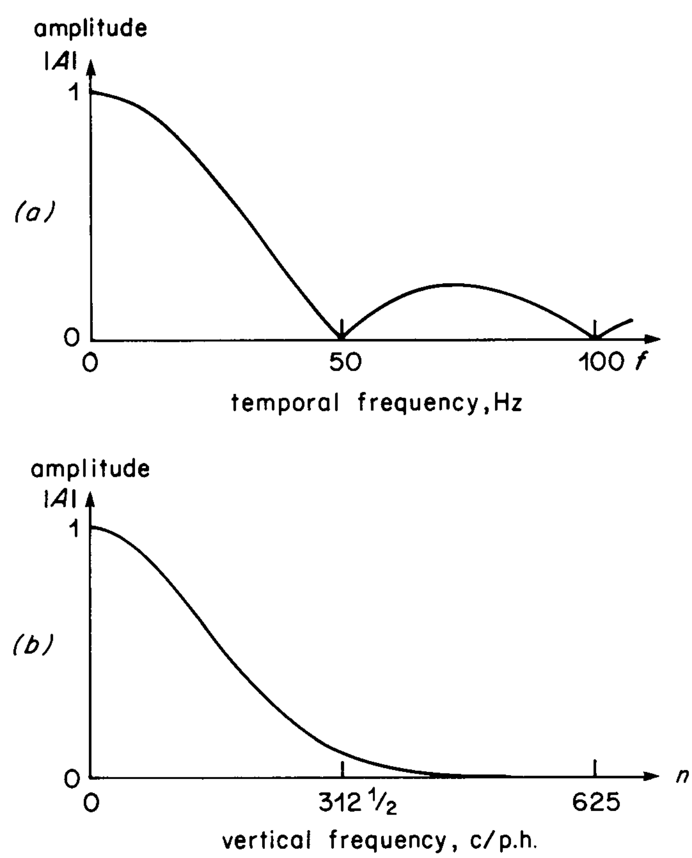

Fig. 2 - Assumed (a) temporal and (b) vertical filtering characteristics for a 625/50/2:1 interlaced television camera.

line structure (components centred on 625 c/p.h. and its harmonics) is adequately suppressed. Because of the slow roll-off, the response for any signal components above about 156 c/p.h. diminishes progressively.

Turning to the temporal response of the display, the CRT does very little to suppress flicker because, with normal persistence tubes, the light

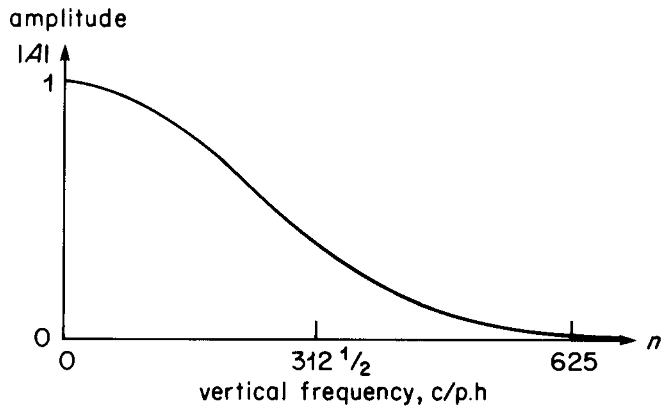

Fig. 3 - A slow roll-off display vertical frequency characteristic showing that some attenuation of wanted low-frequency components occurs in order to adequately suppress the 625-line scanning structure.

output dies away in a few line periods. In fact, therefore, the suppression of field flicker is left almost completely to the eye. After a broad peak in the 7 to 10 Hz region, the perception of flicker is progressively reduced until it becomes imperceptible between about 50 and 75 Hz, depending on the display brightness and the angle subtended at the eye by the screen.

2.2 Image frequencies in sequential and interlaced scanning

From the foregoing description, we can conclude that the range of frequencies carried in the 625/50/2:1 signal is constrained by the 20 ms integration time and the approximate 156 c/p.h. vertical resolution limit of the television camera. If we reconsidet the three potentially equivalent sequential scanning systems in terms of the image frequencies they contain, we would now pick 312/50/1:1 as being the most similar to the interlaced standard. This is because a camera operating with 312/50/1:1 scanning has the same 20 ms integration time as a 625/50/2:1 scan. Also, with a finely focused spot, the sequentially-scanned camera is capable of reproducing (albeit with aliasing) vertical frequencies up to and beyond the half-sampling frequency (156 c/p.h.). Nevertheless, although a 312/50/1:1 signal can contain virtually the same range of image frequencies, the displayed picture quality of 625/50/2:1 is still superior.

The difference in performance stems from the differing nature of the vertical alias components arising with the two scanning methods. These are compared in Fig. 4. With the interlaced scan, Fig. 4(a), the static line structure components are centred on 625 c/p.h. In addition, there are components at 312.5 c/p.h., but these are flickering at 25 Hz and are therefore somewhat less noticeable because of the reduced response of the eye to higher temporal frequencies.

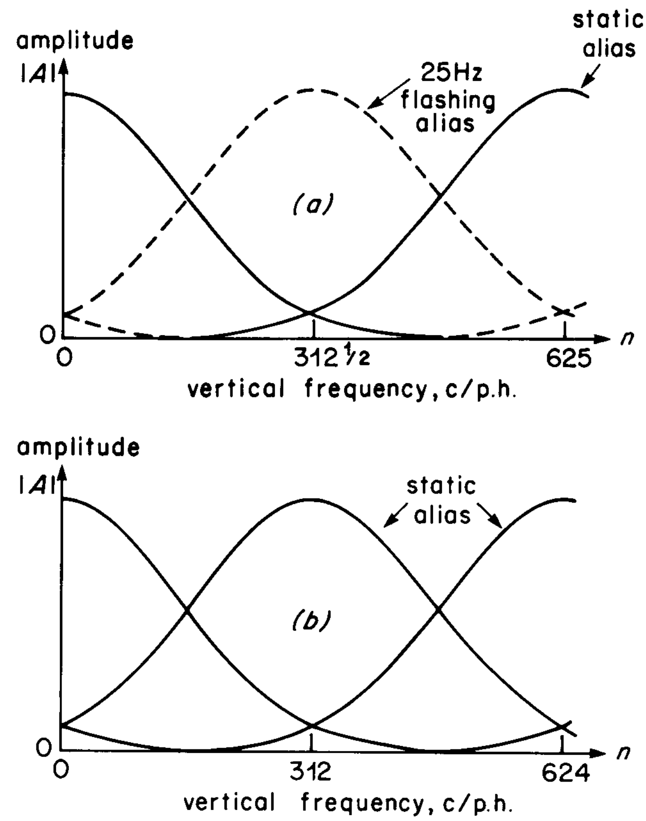

Fig. 4 - Comparison of vertical alias components:

(a) 625/50/2:1 scanning which has the main static line structure components at 625 c/p.h. and (b) 312/50/1:1 scanning in which the main static line structure components are situated at 312 c/p.h.

The baseband signal frequencies carried are the same in the two cases.

Because of this, the vertical characteristic of the CRT display, in spite of its gradual roll-off (Fig. 3), can suppress the line structure without significantly attenuating the wanted baseband components.

In comparison, the sequential scan, Fig. 4(b), has static line structure components at both 312 and 624 c/p.h. So, with the CRT characteristic of Fig. 3, the full resolution of the signal would be displayed, but the line structure components at 312 c/p.h. would not be adequately suppressed. Alternatively, if a lower resolution display were used to suppress the line structure, some of the transmitted information would inevitably be lost.

Thus, we can draw the conclusion that the main effect of interlace is to overcome the slow roll-off vertical characteristic of the CRT. Therefore, in the context of current systems using conventional cameras, it seems appropriate to classify interlace as a method of display improvement. However, if the display had a sharper-cut vertical characteristic, so that the passband could remain relatively flat while still rejecting the repeated spectra, the results with sequential scanning would perhaps be more nearly equivalent.

3. THE INFLUENCE OF NEW TECHNOLOGY

Today's television systems maintain the interlaced structure throughout. This provides the display advantages described in the previous section and avoids the need for scan conversion. However, it is unlikely to yield the most efficient system overall because interlace appears to have no particular benefit at other parts of the signal chain.

With advances in technology, other methods of display improvement can be considered. Indeed, if larger screen sizes and hence wider viewing angles are introduced, the suppression of line structure and flicker frequencies becomes more necessary. These basic scanning impairments can be almost completely suppressed by doubling both the field rate and the number of lines in the picture. This can be achieved without the need for increased signal bandwidth by using up-conversion in the display. Furthermore, developments in digital storage and interpolation have made feasible the use of different scanning methods at other parts of the signal chain. It is therefore possible to take account of the differing requirements of origination, transmission and display by using the most efficient system in each case. This section considers the merits of sequential and interlaced scanning for each stage in the signal chain.

3.1 Display improvement

The up-conversion processes on which display improvement techniques are based synthesise new lines and fields by interpolation. This filters the signal to suppress the nearest spectral components and allows a much greater degree of control of the frequency characteristics involved than is possible with a conventional CRT display. In particular, the up-conversion process could be designed to give a sharper transition between the passband and stopband, appreciably sharper than the slow roll-off CRT display. For example, the number of lines in the picture could be doubled by converting from a sequential 312/50/1:1 signal to a 624/50/1:1 signal. This would make the line structure much less noticeable while, with an appropriately designed interpolator, leaving the wanted baseband frequencies largely unattenuated.

With a sequentially scanned input signal, production of extra lines requires only a single one-dimensional process, using a relatively simple, fixed, vertical interpolator. A reasonably wide bandwidth can be retained because the eye is fairly tolerant to a modest degree of vertical aliasing. With sequential scanning the alias is locked to the picture, which may make it less disturbing than an unrelated alias. Indeed, as is apparent in computer graphics, the presence of this picture-locked vertical aliasing can make edges look subjectively sharper, although the edge positions may be altered. With still pictures, the aliasing is static and therefore less noticeable with the sequential system, having no temporal offset, as with interlace. However, when slow movement is considered, the presence of the alias components may be more noticeable with the sequential system, and it is the eye's tolerance in this situation that will determine how much aliasing can be allowed. Given this tolerance to aliasing, the sequential up-converter can have a relatively flat passband up to 156 c/p.h. and still suppress the line structure, so that the full capacity of the input bandwidth can be used.

The line-rate conversion could be included as part of a more complicated up-conversion process to increase the number of lines further and to perhaps double the field rate of the sequential signal to 100 Hz to ensure the suppression of brightness flicker. In its simplest form, the temporal interpolation could be a field-repeat process, although this would result in some movement judder. Alternatively, with a slightly more complicated arrangement, contributions from adjacent fields could be averaged, giving the appearance of a double edge to a moving image. Although neither of these techniques would be ideal, the levels of impairment would be low. The nature of the impairments would be similar to film judder except that, because double the field rate is used, the extent of the impairment on the picture would be halved for a given rate of movement.

In comparison, up-conversion from an interlaced system, such as 625/50/2:1, has the difficulty that lines from alternate fields cannot be used directly as lines of the current field because of their temporal displacement. Partial compensation for this can be achieved by using a complicated two-dimensional interpolation process[3]. Nevertheless, in the interlace case, temporal aliasing causes vertical and temporal frequencies to share the same spectrum space. In particular, any frequencies in the 312.5 c/p.h. region are overlapped by temporal frequencies of 25 Hz, resulting from movement. Even with adaptive techniques[4,5] it has not yet proved possible to maintain resolution without risking an unacceptable level of judder in motion portrayal. However, this might be relieved using the vector measurement motion compensation techniques to be described in the following section.

In the context of up-conversion, then, sequential scanning has two considerable advantages. First, with the sequential input signal, the up-conversion process can consist of a series of relatively simple one-dimensional interpolation processes. For an interlaced scan, on the other hand, a much more complicated

two-dimensional process is needed. Secondly, the overlap of vertical frequencies with temporal frequencies is reduced in a signal with sequential scanning, so that the two components can be separated more easily than with an interlaced scan.

3.2 Transmission

The difficulty of satisfactory interlaced-to-sequential conversion and the instrumental advantages of sequential scanning for up-conversion in the display suggest that, in this context, it is desirable to use a sequential scan for signal transmission between the television studio and the viewer's receiver. However, in this part of the signal chain it is the bandwidth requirement which is the most important factor. An interlaced signal provides additional spectrum space for static vertical resolution at the expense of moving detail. Whether this is a useful trade-off or not depends on the assumed characteristics of the eye.

It is normally assumed that the eye can resolve substantially more detail in stationary objects than it can if they are moving. While this is true for random or transient motion, the eye can track motion sustained at a constant velocity, thus rendering the moving television image stationary on the retina. In this case, therefore, the capacity for detail may well be comparable to that for the static case. If we accept these arguments on eye-tracking, then as much detail is required for moving objects as for still ones. So on this basis, it is not clear whether the interlaced spectrum is more appropriate for transmission than a sequential one which maintains resolution for moving objects. What other opportunities are there then for bandwidth compression? In particular, could we further exploit the up-conversion process in the receiver?

Whereas spatial techniques of bandwidth compression for television signals have been explored in depth, it is widely accepted that substantial further compression would result from a more effective exploitation of the temporal dimension. Originally the 50 Hz field rate was determined by the electricity supply frequency and flicker requirements, not by movement. If the requirements for flicker suppression in the display were separated from the requirements for movement information in the transmission channel, a substantial reduction in capacity could be made. Thus, although when shot at an update rate of 25 frames per second and displayed at a 50 Hz field rate, film motion suffers from judder, it is expected that the judder could be reduced substantially by applying more effective interpolation, perhaps using movement compensation[6]. This implies that the television field rate could be greatly reduced for transmission. It should be noted, however, that the transmitted signal would not be directly viewable; display processing would therefore form an essential ingredient of any system in which temporal sub-sampling was employed.

When the eye is operating in its transient movement mode, such as for shot changes and random movement, full static detail is not required. This could be exploited by providing reduced resolution in moving areas, if it were not for the effect of eye-tracking. By following sustained, predictable motion and rendering the resulting image stationary on the retina, the eye maintains its capacity for detail. Nevertheless, it would be possible to transmit a reduced number of fields and then to synthesise new intermediate fields at the receiver, provided that suitable interpolation methods could be found.

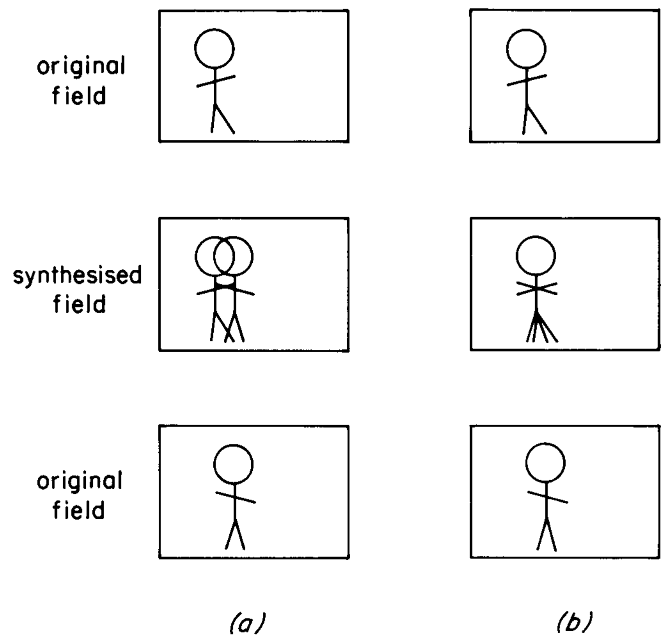

Fig. 5 - Synthesis of intermediate fields using (a) conventional interpolation, which produces a double image, and (b) with movement compensation, which corrects the position of the bulk of the image.

With conventional interpolation, good results can be achieved for slower rates of movement and when the edges of an image are blurred by virtue of the movement. However, with faster movement, particularly with sharper images, a double image is produced by the contributory fields being superimposed, as shown in Fig. 5(a). A much better approach is to use movement compensation in which moving objects are identified and relocated at a position appropriate to the timing of each intermediate field. The result is shown in Fig. 5(b) where, although the movements of the arms and legs are not accurately reproduced, this is less serious because these random movements are subject to the eye's lower capacity for detail. Having the bulk of the object in the correct

position for the tracking observer is much the more important feature.

So, for transmission, the arrangement shown in Fig. 6(a) might be used, in which the up-converting receiver is controlled by a movement compensator. However, successful measurement algorithms, required to quantify accurately the size and direction of movement, are likely to be too complicated for use in a receiver. A much more promising approach is shown in Fig. 6(b) in which the measurements are made at the sending end of the broadcast transmission channel and movement information is then conveyed as an additional signal to the receiver. The new concept of Digitally-Assisted Television (DATV) described in Ref. 7 would have considerable advantages in this application. By sending digitally-encoded movement vectors along with conventional analogue signals, DATV would greatly simplify the receiver because it would no longer need to measure movement. Also, much more complicated movement measurement techniques could be envisaged if they were confined to the sending end of the broadcast link. For example, such principles could be applied within the context of 625/50/2:1 video signals, normal or wide screen, by using the 2 Mbit/s of additional data within a C-MAC system. The signals could then be displayed either directly or in up-converting receivers enhanced by DATV transmission.

In applications using movement compensation, the orthogonal nature of the sequential scan has a further advantage which could be expected to improve and simplify the movement measurement problems. Apart from noise, any difference in the signal between two sequential fields can only be the result of movement in the scene. With interlaced scanning, differences can occur either because of vertical detail or because of movement or both. This is likely to make the design of reliable movement measurement and compensating circuitry significantly more difficult for an interlaced scan.

3.3 Picture origination

A camera operating with 625/50 interlaced scanning does not usually produce appreciable resolution above 156 c/p.h., as shown in Fig. 2(b). However, it is widely assumed that this could be extended towards 312 c/p.h. by improving the

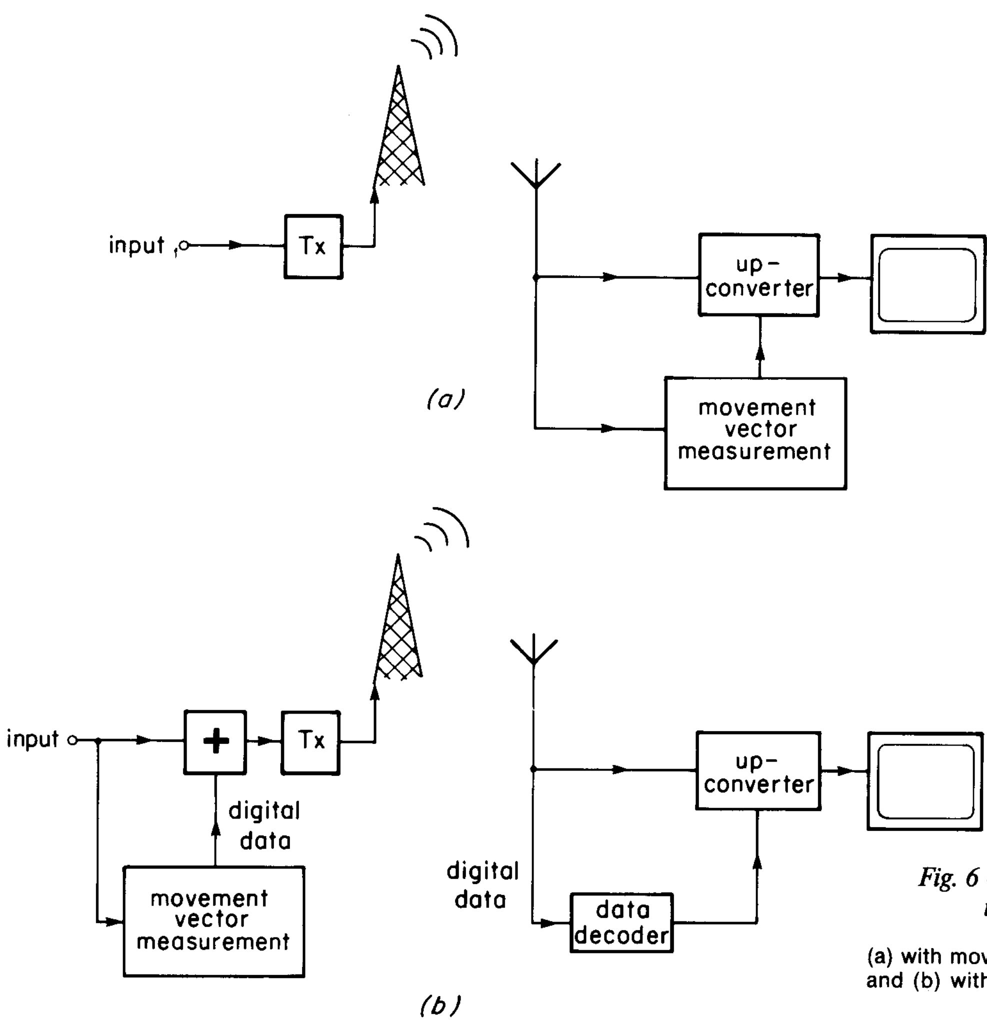

Fig. 6 - Movement compensation for up-converting receivers:

(a) with movement measurement at the receiver and (b) with DATV, used to convey movement vectors to the receiver.

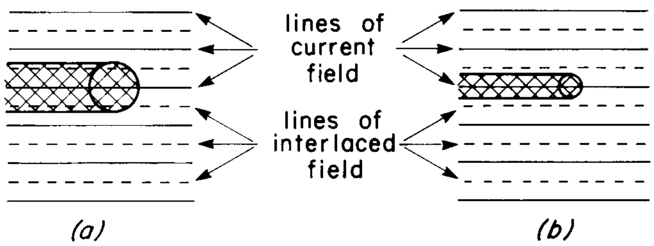

Fig. 7 - The link between vertical resolution and integration time:

(a) the spread of a coarse scanning spot discharges the adjacent line positions (on the interlaced field);

(b) the more finely focused spot misses the adjacent lines so that the charge integrates for a full picture period.

camera, for example by obtaining a finer focus of the discharge beam. As mentioned above, in normal operation the scanning beam discharges the tube target surface at the line positions of both fields, as shown in Fig. 7(a). This limits the integration time to 20 ms. As the spot is made finer to increase the vertical resolution, adjacent line positions will not be fully discharged on each scan, as in Fig. 7(b). Because of this, the integration time tends to increase towards 40 ms, which severely impairs movement. This link between vertical resolution and integration time places, at current field frequencies, a fundamental limitation on the operation of a conventional camera with interlaced scanning.

Other sources used in television, such as electronic graphics, telecines and CCD cameras, are capable of providing more vertical resolution. However, extensive use of this capability leads to a disturbing amount of interlace twitter. Therefore, with current field frequencies, the full vertical resolution cannot be exploited in an interlaced system.

In a sequentially-scanned camera, there is a somewhat different process limiting the resolution. In this case, the integration time is not affected by the fineness of the beam. Even so, the beam width cannot become smaller than the line pitch or parts of the tube surface would be left to build up charge. The low energy nature of the beam ensures that it is attracted to discharge any large aggregation of charge. Because of this, although there is no link with the integration time in a sequential camera, the resolution obtainable cannot be increased to fill the spectrum completely up to 156 c/p.h. In view of this, neither interlaced nor sequential scanning in the camera fills the available spectrum space efficiently.

The opinion has been expressed that the resolution of pictures down-converted to 625/50/2:1 from 1125/60/2:1 HDTV signals can be superior to that obtainable directly from 625/50/2:1 cameras. This suggests a mode of operation in which a finer scanning structure is used in the camera and then the signals are down-converted to achieve more efficient use of the transmission signal spectrum. The down-conversion process would be simplified if the camera used a sequential scan, because there would then be no need to suppress the interlace components of the spectrum. As at the display, conversion from a sequential input can be achieved as a simple one-dimensional process, instead of the complicated two-dimensional conversions needed for interlaced input standards[3]. Another difficulty with interlaced scanning is that the suppression of the interlaced spectral components, being centred on half the field frequency of the sequential scan, will alter the temporal response. This may adversely affect the portrayal of movement.

Because the camera characteristic, Fig. 2(a), does not fully suppress high temporal frequencies in the image, the sampling process results in a considerable amount of temporal aliasing. The presence of this aliasing has the effect of presenting a succession of discrete images to the eye in which much of the spatial detail is preserved. This is well-suited to the tracking mode of the eye which actually prefers further reductions in integration time[8]. From this we can conclude that the inadequate temporal low-pass filtering effect of the camera and the resulting aliasing is sometimes a beneficial part of the television system. Indeed, if the aliasing were eliminated by observing the Nyquist criterion for the 50 Hz field rate, moving objects would be unacceptably blurred. Without aliasing, a very much higher field rate would be required to restore adequate movement portrayal.

Efficient use of the temporal spectrum, similar to the use of down-conversion in the vertical dimension, can be obtained by reducing the integration time, either by shuttering or by using twice the field rate in the camera and ignoring alternate fields. In CCD cameras, the improved read-out noise compared with conventional cameras would allow shuttering and higher scan rates to be used without the inherent reduction of signal-to-noise ratio becoming serious. However, it should be borne in mind that working with an increased level of temporal aliasing in this way would reduce the acceptability of conventional interpolation methods and would necessitate the use of movement compensated up-conversion at the final display.

3.4 Picture processing

Setting aside bandwidth considerations for a moment, the use of sequential scanning in the studio would substantially improve the quality of special effects, slow motion, still frames and other post

production processing techniques. This improvement would result from the removal of the offset between lines of successive fields. For example, a still frame can be read repeatedly without requiring any special processing; with an interlaced source, quite a sophisticated process has to be used to suppress any movement between the two fields of the frame. Whereas this is practicable for the production of a still frame, for the other processes which require real-time operation this normally amounts to assuming that there is no significant difference between the two fields, that is, treating the interlaced fields as though they were sequential by ignoring the presence of any information beyond 156 c/p.h. Applying the alternative of adaptive interlaced-to-sequential processing, which attempts to decide whether frequencies represent motion or vertical detail, it has proved very difficult to achieve satisfactory performance[4,5].

The advantages noted for sequential scanning in transmission and display improvement also apply for a wide range of studio signal processing applications. Thus, the one-dimensional processing advantage, the greater separation of vertical and temporal frequencies and the easier movement measurement of a sequential scan all contribute to providing simpler, more effective processing. For example, it is interesting to note that the NHK HDTV-to-PAL standards converter[9], although converting between two interlaced standards, first converts the 1125/60/2:1 input signal to sequential form (625/60/1:1) to simplify the movement compensated field-rate conversion process. The final conversion to interlaced scanning (625/50/2:1) is then straightforward.

4. EXTENSION TO OTHER SCANNING RATES

Although the foregoing explanation has been in terms of 625/50/2:1 and comparable sequential standards, this has been by way of example. While in most respects the principles can be applied directly to other scanning rates, some aspects of performance do not scale linearly.

The scanning rates can be increased either to provide more lines per picture or more fields per second. If more lines per picture are used, then it may reasonably be assumed that the resolution obtainable from the CRT will be increased proportionately. Ideally, the line pitch at the display should be geared to the CRT resolution, so that the line structure is just adequately suppressed. It can be expected, therefore, that an increase in the number of lines in the picture would provide a proportionate increase in the displayed vertical resolution.

The use of higher field rates, however, can alter the situation in conventional television systems. This is because while the electronic filtering effects of the camera and display may increase with the field rate, the temporal response of the eye does not. Thus, when a higher field rate is used, first, inter-line twitter is less noticeable and, secondly, the link in an interlaced camera between vertical resolution and integration time becomes less important. Accordingly, the vertical resolution could be increased by using a more finely focused spot because the blurring of movement would be proportionately less. In terms of the equivalence discussed earlier, the characteristics of the interlaced scan would then be more similar to those of a sequential scan having the same number of lines per picture, but half the number of fields per second. The disadvantage in either case would be the increase in signal bandwidth needed to support the higher field rate.

With up-conversion, it is possible, in principle at least, to separate the requirements for movement portrayal from those for flicker suppression. Therefore, the use of a higher field rate at the display would produce less flicker, whereas a higher field rate for transmission would improve movement. This freedom to determine the performance characteristics separately would simplify the problems of optimising the system performance within a given bandwidth.

5. CONCLUSIONS

For television systems consisting of conventional television cameras and cathode-ray tube displays, interlaced scanning has clear advantages over comparable sequential systems. This supremacy arises because the line structure components in the vertical frequency spectrum are more easily suppressed by the slow roll-off vertical frequency characteristic of a CRT display. Nevertheless, the range of image frequencies carried by a sequential scan with the same field rate and half the number of lines could be comparable to that of an interlaced scan.

Advances in signal processing techniques have made it possible to consider new television systems in which the scanning processes used in signal origination, studio processing, broadcast transmission and display can, if appropriate, be different. In particular, the use of up-conversion could overcome the disadvantage of conventional displays for sequential scanning to allow the full resolution carried by the signal to be displayed. Furthermore, because the conversion process is simpler for a sequential input, the field rate of the display could also be increased to reduce flicker.

The desirability of sequential scanning at the display input strengthens the possible advantages of using a sequential system for broadcast transmission. Coupled with movement compensation techniques,

this might allow the transmitted field rate to be reduced to a point which is adequate for movement portrayal, while using a higher field rate in the display for flicker suppression. In this context, the use of DATV would provide a substantial advantage by making the complicated movement measurement process the responsibility of the broadcaster, rather than being needed in each receiver. Throughout these new systems, therefore, the relative advantages of sequential and interlaced scanning should be carefully examined with a view to using the optimum system in each part of the television signal chain.

6. REFERENCES

1. BURNS, R.W. 1986. British Television, the Formative Years. London, Peter Peregrinus, 1986.

2. BALLARD, R.C. 1932. Improvements in or relating to Television Systems. UK Patent No. 420,391. Application date: 19th July 1933.

3. CLARKE, C.K.P. and TANTON, N.E. 1984. Digital Standards Conversion: Interpolation theory and aperture synthesis. BBC Research Department Report No. BBC RD 1984/20.

4. ROBERTS, A. 1983. The Improved Display of 625-line Television Pictures. BBC Research Department Report No. BBC RD 1983/8.

5. ROBERTS, A. 1985. The Improved Display of 625-line Television Pictures: Adaptive Interpolation. BBC Research Department Report No. BBC RD 1985/5.

6. THOMAS, G.A. 1987. Television Motion Measurement for DATV and other Applications. BBC Research Department Report No. BBC RD 1987/11.

7. STOREY, R. 1986. HDTV Motion Adaptive Bandwidth Reduction using DATV. IBC 86. IEE Conference Publication No. 268, pp 167-172.

8. GURLEY, M. and HASLETT, C.J., 1985. Resolution Considerations in using CCD Images in Broadcast-quality Cameras. SMPTE Journal September 1985, pp 882-895.

9. TANAKA, Y. et al. 1986. HDTV-PAL Standards Converter. NHK Laboratories Note No. 326, January 1986.